Appendix C: Supporting Documentation for Watershed Characterization, Part I

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Using Appendix C

The purpose of this appendix is to provide the detailed methods, results, and supporting documentation that are the underpinnings of the main body of the report but to detailed or extensive to report there. This appendix follows the order in which the individual steps are presented in our methods document (Gersib et al. 2004). Individual steps were included in this appendix only if methods were changed or where detailed results needed to be documented.

Establish Spatial Scales of Analysis

Watershed characterization is a process of placing individual natural resources into a landscape context. Multiple spatial scales can define the area of potential impacts of a transportation project, facilitate the characterization of ecological processes, and define the potential boundaries for mitigation or compensation of project impacts.

Methods used to develop spatial scales follow Gersib et al. (2004).

Project Study Area

Results of the I-405 / SR-520 project study area delineation are presented in the main document, Figure 23.

Subareas

Subarea boundaries used in this characterization project were established by the WRIA 8 Near-term Action Agenda (WRIA 8 Steering Committee 2002) and are presented in the main document, Figure 24.

Drainage Analysis Units

Drainage Analysis Units (DAU) are defined as surface catchments ranging from approximately 200 to 2,000 acres in size. This spatial scale is used to characterize the condition of ecological processes and is assumed to represent landscape areas of relatively uniform land use. Delineation procedures are consistent with King County hydrology modeling to facilitate use of the data. DAUs developed for this characterization project are presented in the main document, Figure 26.

Establish Temporal Scales of Analysis

While project impact assessment only requires an understanding of the current state of natural resources, mitigation decision-making requires an understanding of future land use conditions and an ability to evaluate if potential mitigation sites are capable of maintaining their area and function over the long-term. In addition, the characterization of ecological process condition requires an understanding of land use change over time.

Characterize Pre-Development Conditions

Pre-development land cover condition is a data layer that is the reference point for assessing the current and future state of natural resources within the project area. An assessment of landscape condition requires an understanding of the extent of change in ecological processes from a pre-development to present and future land use conditions.

Methods

Methods follow Gersib et al. (2004) Part I, Step 2A

Results

Coniferous forest covered most of the glacial drift plains, hill slopes, and confined stream valleys in the study area prior to European settlement. Douglas fir dominated on dry slopes and areas disturbed by fire and landslides. Because of its higher shade tolerance, western hemlock dominated in wetter areas that were infrequently disturbed. Western red cedar was concentrated near wetlands and stream bottoms.

Reconstruction of historic land cover conditions in the Stillaguamish River Basin (Pollock 1998) and the Snohomish River Basin (Gersib et al. 1999) provides additional insight into pre-development land cover within the two major watersheds immediately north of the project study area. Both studies indicate that outside of floodplains the Puget glaciated lowland was dominated by coniferous trees. Using General Land Office (GLO) data, Pollock found that while late-successional (old growth) coniferous forests were the most common upland forest type, a variety of successional stages were present. GLO data in the Snohomish basin indicated that glaciated upland areas consisted of 80 percent coniferous forest species with over 40 percent of coniferous trees in the mid- to late-seral stages (Tables C-1 and C-2).

Forested wetlands and shrub-dominated sphagnum bogs were often found on depressions within glacial deposits. These depressional wetlands are commonly associated with Orcas Peat, Seattle Muck, Shalcar Muck, and Tukwila Muck soils.

Groundwater in glacial outwash deposits was usually near the surface in the study area. Glacial outwash prairies were therefore rare, since these prairies typically develop on dry, well-drained outwash deposits such as those found in the South Puget Sound region.

Forests in unconfined stream valleys were frequently disturbed by flooding and channel migration. These floodplain forests were therefore dominated by hardwood deciduous trees. General Land Office survey notes for meandering reaches of the Snoqualmie River show red alder, willows, vine maple, big-leaf maple, and Pacific crabapple as the most common streamside trees (Collins and Sheikh, 2002). Large conifers were rare, but accounted for nearly half of the dead wood biomass in rivers and streamside forests. Conifers were more common on floodplain areas further from streams, but still accounted for only 21 percent of trees. GLO notes also show an abundance of small deciduous trees in the Stillaguamish River floodplain (Pollock, 1998).

An extensive wetland complex covered most of the Sammamish River valley floor. Lake Washington was 9 feet higher than it is today, and Lake Sammamish was about 6-feet higher (Tetra Tech, Inc., 2002). Lake Washington fluctuated by several feet over the course of a typical year. The lower reaches of the Sammamish River were inundated by the lake, and backwater effects extended upstream to Lake Sammamish. This created a complex mosaic of forested wetlands, emergent wetlands, shrub-dominated wetlands, riparian forest, and upland forest on the Sammamish valley floor. Construction of the Lake Washington Ship Canal in 1917 drained most of these wetlands, and stabilized water levels in Lake Washington.

Table C1. Pre-development Land Cover by Geologic Grouping From General Land Office Data (Gersib et al. 1999).

Plant Association By Geologic Grouping	**Specimen Tree Seral Stage – Number in Sample (percent of total)**				**TOTALS**
	Young (<12” DBH)	**Early (12”-<20” DBH)**	**Mid (20”-36” DBH)**	**Late (>36” DBH)**	
Bedrock					
Coniferous	238 (21 percent)	306 (27 percent)	469 (41 percent)	124 (11 percent)	1137 (100 percent)
Deciduous	71 (67 percent)	18 (17 percent)	13 (12 percent)	4 (4 percent)	106 (100 percent)
Glacial Course Sediment					
Coniferous	87 (26 percent)	95 (28 percent)	112 (33 percent)	42 (13 percent)	336 (100 percent)
Deciduous	66 (73 percent)	8 (9 percent)	11 (12 percent)	6 (7 percent)	91 (101 percent)
Glacial Fine Sediment					
Coniferous	225 (34 percent)	167 (25 percent)	195 (29 percent)	82 (12 percent)	669 (100 percent)
Deciduous	120 (72 percent)	14 (8 percent)	24 (14 percent)	9 (5 percent)	167 (99 percent)

Table C2. Comparison of Coniferous vs. Deciduous Forest Land Cover by Geologic Grouping From General Land Office Data (Gersib et al. 1999).

Surficial Geology Type	Number and Proportion of Specimen Trees by Plant Association		Totals
	Coniferous	Deciduous	
Glacial Course Sediments	336 (79 percent)	91 (21 percent)	427 (100 percent)
Glacial Fine Sediments	669 (80 percent)	167 (20 percent)	836 (100 percent)
Bedrock	1137 (91 percent)	106 (9 percent)	1243 (100 percent)

Characterize Current Land Cover Conditions

Current land cover condition is a data layer showing existing conditions in the study area. We use current land cover data to compare current conditions with pre-development land cover, in order to gain perspective on the extent of change in land cover over time. We also use current land cover data to calculate key landscape attributes needed to characterize the extent of alteration in ecological processes.

Methods

Methods follow Gersib et al. (2004) Part I, Step 2B.

Results

Current land cover data used in this project were developed by King County in 2001 using 1998 remote sensing data. Current land cover data for the project study are presented in Figure C-6.

Characterize Future Land Cover Conditions

Future land cover condition is a data layer showing predicted future conditions in the study area. Conventional methods for identifying and assessing potential mitigation sites primarily focus on assessing a site's ability to mitigate project impacts under current conditions. We additionally seek to understand the future development pressures that will influence a site's ability to maintain environment functions. Surrounding land use influences how a site functions. This approach helps resource managers gain a better understanding of a mitigation site's potential to mitigate project impacts and maintain environmental function over the long-term. We assume that resource impacts are permanent. Mitigation sites must be screened to ensure they have the greatest potential to replace and maintain functions over the long-term.

Methods

We developed future land cover from a combined digital coverage of city and county comprehensive plans, compiled by the Puget Sound Regional Council. Classification codes and descriptions differ for land use classes in the different jurisdictions. We developed a common classification scheme, by analyzing the comprehensive plans and assigning each land use class into a broader generic class.

We then assigned a total impervious area (TIA) percent to each of those generic classes. We assumed wetlands and steep slopes (greater than 30 percent slope was considered steep) would not be developed regardless of the comprehensive plan designation. We also assumed that land use intensity would not decline in the future, so where there were DAUs that showed improvement in the future, we used the current functional rating.

Using this information, we calculated the future percent TIA for each DAU. We gave the DAUs a functional rating of “properly functioning,” “at risk,” or “not properly functioning” for future percent TIA, using the same criteria for calculating a TIA condition rank under current conditions. We then evaluated the new percent TIA condition rank with the condition rank for percent forest cover to establish an overall future condition rank for the delivery of water.

Results

Future TIA data for the project study area are presented in Figure C-7.

Characterize Condition of Process Drivers

Understanding natural resources, and the ecological process drivers that create and maintain them, is the foundation of this watershed characterization work. This understanding establishes the landscape context from which to identify and prioritize potential mitigation options. To establish this context, information was compiled on the location, extent, and condition of wetland, riparian, and floodplain resources, condition of fish and wildlife habitats, and the effects of human land use on surface and subsurface flow of water within the study area. To gain understanding, this information was compiled by individual team members and then presented to the interdisciplinary technical team. The following summarizes our findings.

Characterize Surface/Subsurface Flow

The movement of water through the landscape is governed by interactions between precipitation, land cover, soils, and geology. A key step in watershed characterization is to understand how these factors influence the routing and delivery of water, sediment, and pollutants. In Chapter 3 of the main document, we describe the hydrology of each subarea in the study area. Methods and results that apply to the study area as a whole are summarized below.

Methods

The geology of the study area, shown on Map C-8, Surficial Geology in the Study Area, was derived from the Department of Natural Resources (DNR) 100K geology maps. DNR's geologic units were generalized into the following categories to reflect our focus on the glaciated Puget Lowlands, as shown in Table C-3.

Table C-3. DNR Surficial Geology Units in the Puget Lowlands.

Generalized Geology Category	**DNR Surficial Geology Units**
Alluvium	Qa, Qc, Qcg
Landslides	Qls
Peat	Qp
Recessional Outwash	Qgo, Qgo(i)
Glacial Till	Qgt
Advance Outwash	Qga, Qga(t)
Pre-Fraser and Interglacial Deposits	Qgu, Qgp, Qgpc
Sedimentary Rock	Ec(2pg), Ec(2r), Em(2r), OEn
Volcanic Rock	Eian, Eib, Evc(t), Mvc(2), OEva, OEvb, Oian

Soils data for the study area, shown in Map C-9, Soil Types in the Study Area, was derived from GIS coverages of the USDA soil surveys for King and Snohomish Counties. Again, the detailed USDA soil classifications were generalized and lumped into categories relevant to hydrologic analysis, as shown in Table C-4.

Table C-4. USDA Soil Types.

Generalized Soil Category	**Hydrologic Soil Group**	**USDA Soil Types**
Alluvial	C or D	Briscot silt loam Earlmont silt loam Mixed alluvial land Oridia silt loam Pilchuck loamy fine sand Puget silty clay loam Renton silt loam Sammamish silt loam Si silt loam Snohomish silt loam Sultan silt loam Woodinville silt loam Pits
Well-drained Alluvium	B	Newberg silt loam Puyallup fine sandy loam
Colluvial	B	Beausite gravelly sandy loam
Depressional	D	Bellingham silt loam Norma sandy loam Custer fine sandy loam McKenna gravelly silt loam
Wetland	D	Orcas peat Seattle muck Shalcar muck Tukwila muck Mukilteo muck
Lacustrine	C	Kitsap silt loam
Glacial Outwash	A or B	Arents, Everett material Everett gravelly sandy loam

		Indianola loamy fine sand Neilton very gravelly loamy sand Ragnar fine sandy loam Ragnar-Indianola association Lynnwood loamy sand
Glacial Till	C	Alderwood and Kitsap soils Alderwood gravelly sandy loam Arents, Alderwood material Ovall gravelly loam Tokul gravelly loam
Mixed Till and Outwash	A and C	Everett-Alderwood gravelly sandy loams

Groundwater aquifers and flow paths were identified using information compiled by Liesch et al. (1963), Vacarro et al. (1998), Ecology's well log database, and local groundwater management plans. Groundwater recharge was characterized by analyzing the distribution of glacial outwash deposits. Loss of recharge from development was measured by the extent of impervious surfaces covering outwash deposits.

Stream basin hydrology was analyzed by dividing the study area into 22 major catchments (See Map 25 in the main document, Stream Catchments Used in the Analysis). Catchments were selected to represent the drainage areas typically used by local jurisdictions in stormwater management and resource recovery plans. These were further subdivided in some case to separate out project impacts for specific streams within the larger catchment.

For each catchment we reviewed existing hydrologic data and studies to characterize groundwater flow, surface runoff, and water quality. We combined soils data with the conceptual model developed by Dinicola (2001) for lowland glaciated terrain to describe how runoff was generated under pre-developed forested conditions. Land cover data were then analyzed to identify the extent of hydrologic alteration in the catchment, using percent TIA and Forest Cover as the key metrics. Local drainage and modeling study results were summarized to further identify drainage system alterations and impacts to flow regimes. Estimates of peak flow statistics for streams were compiled from the King County Flood Insurance Study (Federal Emergency Management Agency 1989) and WSDOT's Hydraulics Manual (1997). The project wetland database was reviewed to characterize the role of wetlands and natural storage features in catchment hydrology under pre-developed and existing conditions.

Major water quality issues for each catchment were identified from Ecology's 2004 303(d) List of Impaired Waters, King County's Streams Monitoring Program (King County Department of Natural Resources, 2004), and various studies performed in the area by the US Geological Survey National Water Quality Assessment Program (1998 and 1999). Stream geomorphology was assessed using observations of channel conditions from the project fish habitat survey for this project conducted by Kurt Buchanan of the Washington State Department of Fish and Wildlife, supplemented by other local studies where available.

Results

Most of the study area is covered by several hundred feet of glacial deposits (Figure C-1). The uppermost layer is usually till, made up of fine material that has been compressed and cemented into hardpan by glacial ice. The till is underlain by sands and gravels deposited by meltwater from advancing glaciers (advance outwash). Valleys are often covered by meltwater deposits from receding glaciers (recessional outwash). Post-glacial floods in the Evans Creek, Issaquah Creek, lower Little Bear Creek, and Sammamish River valleys have reworked the glacial deposits and covered the valley floors with alluvium. Recessional outwash often remains as terraces on the margins of these alluvial valleys. North Creek and the Lake Washington drainages cut directly through advance and recessional outwash deposits, and have not developed extensive alluvial floodplains. Bedrock is exposed only in higher elevations within the Issaquah Creek basin.

Till has low permeability, and is usually covered by about 3-feet of sandy loam soil. Most rainfall infiltrates through the sandy loam layer before hitting the hardpan, where it runs off towards streams as shallow subsurface flow. A small portion of rainfall infiltrates downward through the hardpan to recharge aquifers in the underlying advance outwash.

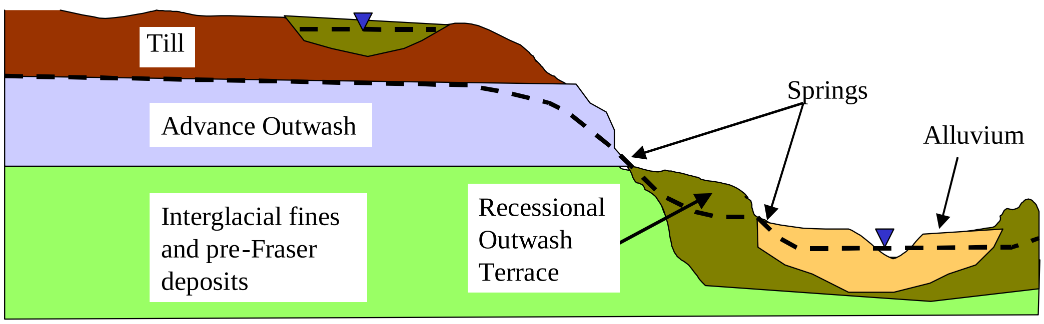

Figure C-1. Idealized Geologic Section Showing Study Area Aquifers.

In forested landscapes storm runoff will be slow until enough rain has fallen to bring groundwater to the surface in the valley bottoms and terraces (Dinicola, 2000). These saturated areas will then generate overland flow into streams, and produce the high flow events that shape natural stream channels. Land clearing and development fundamentally change these runoff processes by compacting and paving soils, and directing runoff into storm drainage systems. Stream catchments in the Lake Washington and lower Sammamish River basins have been highly altered by development, with TIA of between 24 and 68 percent. The lowest levels of hydrologic modification are found in the Issaquah Creek basin, where catchment TIA is generally between 12 and 14 percent.

Groundwater recharge is greatest where outwash deposits are exposed at the surface. These deposits are highly permeable, and under natural conditions generate little runoff unless they are saturated by rising groundwater. Recessional and advance outwash deposits are exposed in 29 percent of the study area. 32 percent of these areas are now covered by impervious surfaces.

Advance outwash aquifers are partially confined between till and interglacial deposits. Groundwater in these aquifers flows roughly parallel to the surface topography towards stream valleys and lakes (Vacarro et al., 1998). Springs and seepages zones often emerge in ravines and on the margins of valleys where erosion has exposed the advance outwash. These are important sources of recharge for unconfined aquifers and streams on the valley floors. Juanita, North, Little Bear, Valley, Forbes, and Yarrow creeks arise from advance outwash that is exposed in headwater valleys.

Advance outwash deposits are broken up by stream valleys, and do not form a single connected aquifer. Important units of advance outwash include the Interlake, Sammamish Plateau, North/Little Bear, and Bear/Evans (Liesch et al., 1963). Unconfined groundwater is found in coarse recessional outwash deposits. In valleys with major alluvial deposits this groundwater flows through terraces to recharge the alluvial aquifer. In other valleys the recessional outwash acts as an alluvial aquifer. Streams with high channel complexity will have high rates of hyporheic flow between the alluvial aquifer and the streambed. This exchange between the stream and the aquifer buffers and moderates stream temperatures.

Major groundwater users were identified from WSDOT's GIS coverage of Group A Wellhead Protection areas, and include the Cross Valley Water District, the City of Redmond, Sammamish Plateau water and sewer districts, and the Issaquah Water Association. Beaux Arts Village and King County Water Districts #1 and #17 pump groundwater from advance outwash near Lake Washington.

Figure C-10, Sole Source Aquifers and Critical Aquifer Recharge Areas, shows sole source aquifers and Critical Aquifer Recharge Areas in the study area. The I-405 project does not intersect any regulated aquifer protection zones or critical recharge zones. The eastern terminus of the SR-520 project lies within the City of Redmond's aquifer protection zones. Redmond is developing a Critical Aquifer Recharge Area ordinance for these zones that focuses on the storage and handling of hazardous materials and other potential sources of groundwater pollution. King County has designated Critical Aquifer Recharge Areas within the East Sammamish Plateau and Issaquah Creek basins. The US EPA has designated the Cross Valley Water District as a sole source aquifer.

Characterize Wetland Resources

Wetlands are considered to be a key ecological process driver because of their potential to influence the delivery and routing of water, sediments, pollutants, and heat. Identifying the location, extent, and condition of wetlands within the study area provides valuable insight into a landscape's capacity to maintain ecological processes that influence water quality, water quantity, and fish and wildlife habitats. Existing, degraded, and destroyed wetlands also serve as the pool of potential mitigation sites for project impacts to wetlands.

Methods

We compiled available wetland data and converted it into an ArcMap data layer. Wetland data sources used include U.S. Fish and Wildlife Service National Wetlands Inventory, DNR 1:24,000 hydrography, Washington Department of Fish and Wildlife Priority Habitat and Species, hydric soils data from DNR originally developed by the U.S. Department of Agriculture, King County wetlands coverage, and wetland data from the Cities of Kirkland and Bothell.

Following methods described in Gersib et al. (2004), we interpreted aerial photos of wetland sites and created a GIS database that identifies the location and extent of existing, degraded, and destroyed wetlands with restoration potential. For this analysis, we used 1:12,000 color stereo-paired photos taken in July, August, and September of 2001 and available wetland information. For each potential wetland polygon established, we determined current land use, potential for restoration, hydrologic alteration, vegetative alteration, present hydrogeomorphic wetland class, potential hydrogeomorphic class, and sites with preservation potential.

Results

The potential wetland restoration ArcMap data layer is provided on an attached compact disk.

Characterize Riparian Resources

Riparian areas are an important natural resource. They influence how water, sediment, nutrients, and large wood are delivered to and routed through a stream system. We identified and assessed the condition of stream riparian areas within a large part of the project study area. This serves as a tool for characterizing key ecological processes, and as a means of identifying potential mitigation opportunities.

Methods

We created an ArcMap data layer to which we compiled data on potential riparian restoration sites within the study area. Available data used to assess riparian condition include DNR 1:24,000 hydrography, 1998 orthophotos, and color stereo-paired aerial photos taken in July, August, and September of 2001.

We established 33-meter and 67-meter stream buffers using DNR hydrography. The 33-meter buffer provides insight into the condition of the riparian system and its ability to provide stream shading for temperature attenuation and corresponds with local government agencies 100-foot buffer for planning under local critical areas ordinances. The condition of the 67-meter buffer is used to provide an understanding of habitat connectivity, water quality and quantity benefits, and potential for recruiting large woody debris (LWD) and is based roughly on site potential tree height.

Non-forest areas within the riparian buffers were delineated using GIS and both orthophotos and color stereo-paired aerial photographs. Following methods described in Gersib et al. (2004), we created a polygon and a corresponding database file for each non-forested riparian area. For each polygon established, we determined current land use, potential for riparian restoration, potential to add to an existing forest patch, potential to reconnect two fragmented forest patches, and adjacency to schools and public lands.

Potential riparian areas overlapping existing or potential wetlands were deleted for the dataset. These sites occurred either when wetlands were drained and the drain now functions as a stream or when non-forested emergent wetlands occurred. The reforestation of this artificial riparian area has potential to preclude restoration of the historic natural resource or the degradation of properly functioning wetlands should be avoided. Remaining potential riparian restoration sites were then screened by size, with sites less than three acres deleted from the dataset.

Results

The potential riparian restoration ArcMap data layer is provided on an attached compact disk.

Characterize Floodplain Resources

Floodplain areas represent a mosaic of stream, riparian, and wetland types. They are a third natural resource that influences how water, sediment, nutrients, and large wood are delivered to and routed through a stream system.

Methods

We created an ArcMap data layer to which we added data on potential floodplain restoration sites within the study area. Available data used to assess overall floodplain condition include DNR 1:24,000 hydrography, 1998 orthophotos, color stereo-paired aerial photos taken in July, August, and September of 2001, FEMA floodplain boundaries, and light detecting and ranging (LIDAR) data.

We identified diked areas that decouple the floodplain from the river and have little or no restoration potential due to development, using the orthophotos, the color stereo-paired aerial photographs, and LIDAR data. Following methods described in Gersib et al. (2004), we created a GIS polygon and a corresponding database file for each floodplain area. For each floodplain polygon established, we determined current land use, potential for restoration, potential to allow channel migration, and adjacency to schools and public lands.

Results

The potential floodplain restoration ArcMap data layer is provided on an attached compact disk.

Characterize Condition of Ecological Processes

We seek to target mitigation activities to areas having the greatest potential to benefit from environmental investments. To do this, we need to better understand the landscape-scale condition of aquatic and terrestrial resources and fish and wildlife habitats. Further, understanding the condition of ecological processes establishes a context for assessing mitigation alternatives.

Methods

Methods for the characterization of ecological processes follow methods described in Gersib et al. (2004).

Ecological processes characterized and landscape attributes used in the characterization process area presented in Table C-5.

Table C-5. Landscape Attributes Used to Characterize Target Ecological Processes.

Targeted Ecological Processes	Landscape Attributes Used in Assessment
Delivery of Water	Total Impervious Area Percent Forest Area
Delivery of Sediment	Bare Soils Road Density Unstable Slopes
Delivery of Large Woody Debris	Percent Riparian Forest Number of stream crossings
Aquatic Integrity	Percent Riparian Forest Percent Total Impervious Area Benthic - Index of Biological Integrity
Upland Habitat Connectivity	Patch Cohesion Index Area-weighted mean radius of gyration Percentage of Landscape in Forest Class

Characterizing the condition of an ecological process, like the delivery and routing of water, is the result of understanding the effect of human land use on two distinct components, the delivery of water (for example, the speed and method by which water is delivered to a stream system) and the routing of water (for example, the speed and means by which water moves, once it reaches a stream system). Land use patterns alter the delivery and routing of water, sediment, pollutants, large wood, and heat through a stream system. When this occurs, we make a fundamental assumption that the first and foremost priority, when seeking measurable environmental improvement, is to target the delivery component of the ecological process. Keeping excess water, sediment, etc. out of the stream system focuses on the source or core problem. Recovery efforts that seek to remove or manage the problem once it is in the stream are very different.

We assign a condition rank to each DAU for each landscape attribute used in the characterization of an ecological process. This ranking is based on criteria established and described in the detailed methods of Gersib et al. (2004). The condition of each landscape attribute and ecological process are grouped into general condition categories of “properly functioning,” “at risk,” or “not properly functioning.” when multiple landscape attributes were used to determine the condition of an ecological process, we established and followed a set of rules to assign an overall condition rank for each ecological process by DAU. Rules used to establish the overall condition rank follow Gersib et al. (2004).

In the case of the overall condition for the water, we follow the characterization of ecological processes under current land cover conditions with the creation and analysis of a future build-out scenario. This was developed and used to characterize the delivery of water under future land cover conditions.

We developed future land cover from a combined digital coverage of city and county comprehensive plans, compiled by the Puget Sound Regional Council. Classification codes and descriptions differ for land use classes in the different jurisdictions. We developed a common classification scheme, by analyzing the comprehensive plans and assigning each land use class into a broader generic class.

We then assigned a TIA percent to each of those generic classes. We assumed wetlands and steep slopes (greater than 30 percent slope was considered steep) would not be developed regardless of the comprehensive plan designation. Using the generic classes, we calculated the future TIA for the entire study area by individual DAU. We gave the DAUs a functional rating of “properly functioning,” “at risk,” or “not properly functioning” based on TIA, using the same criteria as were used for current conditions (see above). We also assumed that the situation would not improve, so where there were DAUs that showed improvement in the future, we used the current functional rating.

The one exception to this methodology is characterizing upland habitat connectivity. For characterizing the landscape condition of this ecological process we used the Fragstats statistical tool and analyzed the association of forest and non-forest patches using available land cover data. Due to the importance of assessing larger landscape scales when evaluating habitat connectivity, we decided to conduct our characterization of this ecological process at the stream catchment scale, rather than the smaller DAU scale used to characterize other processes. Detailed methods are included in the upland habitat connectivity results that follow.

Results

Delivery of Water: Landscape attributes used to characterize the delivery of water include percent total impervious area, and percent forest cover. Calculations for each attribute by DAU, the condition rank of two landscape attributes, and the final condition rank for the deliver of water is presented in the Excel spreadsheet file: DAU Condition Results 11_2_04.xls on the attached compact disk. The condition rank by DAU of each landscape attribute used to characterize the delivery of water in the study area is shown in Figure 27 in the main document, while Figure 28 in the main document is a map showing the overall condition rank of each DAU for the delivery of water, under current land cover conditions.

Revised total impervious area results based on the future build-out scenario are presented in the Excel spreadsheet file: Future DAU Data.xls on the attached compact disk. Revisions to the percent total imperious area condition rank were then combined with existing results for percent forest cover to create a final condition rank for the deliver of water under the future build-out scenario. Table C-6 shows which DAUs had a changed final condition rank for the delivery of water under the future build-out scenario. The current rank is shown for comparison.

Table C-6. DAUs with Changed Overall Rank for the Delivery of Water.

DAU	Subarea	Current Ranking	Future Ranking
11	North Creek	AR	NPF
39	Sammamish River	AR	NPF
40	Sammamish River	AR	NPF
50	Bear Creek	AR	NPF
51	Bear Creek	AR	NPF
106	Kelsey-Mercer Creek	AR	NPF
114	Lake Sammamish	AR	NPF
115	Lake Sammamish	AR	NPF
117	Lake Sammamish	AR	NPF
129	Lake Sammamish	AR	NPF
130	Lake Sammamish	AR	NPF
133	Lake Sammamish	AR	NPF
136	Lake Sammamish	AR	NPF
182	Issaquah Creek	PF	AR

Results indicate that the condition rank for the delivery and routing of water will change in 14 of the 184 DAUs, based on anticipated future land use change. Thirteen DAUs will change from “at risk” to “not properly functioning” and one DAU is expected to change from “properly functioning” to “at risk”. Specific information related to these expected condition changes in the delivery of water are summarized in the Excel spreadsheet file: Future DAU Data.xls.

Delivery and Routing of Sediment: Landscape attributes used to characterize the delivery and routing of sediment include percent bare soils, road density, and percent unstable slopes. Calculations for each attribute by DAU, the condition rank of each landscape attribute, and the final condition rank for the deliver and routing of sediment is presented in the Excel spreadsheet file: DAU Condition Results 11_2_04.xls on the attached compact disk. Figure 29 in the main document is a map of the study area with the condition rank by DAU of each landscape attribute used to characterize the delivery and routing of sediment, while Figure 30 in the main document is a map showing the overall condition rank of each DAU for the delivery and routing of sediment, under current land cover conditions.

Delivery and Routing of Large Wood: Landscape attributes used to characterize the delivery and routing of large wood include percent riparian forest and the number of stream crossings. Calculations for each attribute by DAU, the condition rank of two landscape attributes, and the final condition rank for the deliver and routing of large wood is presented in the Excel spreadsheet file: DAU Condition Results 11_2_04.xls on the attached compact disk. Figure 31 in the main document is a map of the study area with the condition rank by DAU of each landscape attribute used to characterize the delivery and routing of large wood, while Figure 32 in the main document is a map showing the overall condition rank of each DAU for the delivery and routing of large wood, under current land cover conditions.

Aquatic Integrity: Landscape attributes used to characterize aquatic integrity include percent riparian forest, total impervious area, and available Benthic-Index of Biological Integrity (B-IBI) scores. Percent riparian forest and percent total impervious area calculations were made by DAU and the condition rank for each of the two landscape attributes was mapped, along with the point location and score of all available B-IBI data. Following established rules presented in Gersib et al. (2004), a final DAU condition rank was established for aquatic integrity. Calculations and results are presented in tabular form in the Excel spreadsheet file: DAU Condition Results 11_2_04.xls on the attached compact disk. Figure 33 in the main document (Condition Map for Aquatic Integrity) is a map of the study area with the condition rank by DAU of each landscape attribute used to characterize aquatic integrity and the B-IBI score. Table C-7 presents the B-IBI scores we were able to collect from other researchers in the study area.

Table C-7. B-IBI scores for streams in study area from 1995 through 2002.

Water Body	Site Name, Number, or Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	Recent	Source
Bear	Middle Bear Creek u/s 133rd St.	34		28		26	16				16	1, 4
Bear	Rutherford Creek							30			30	1
Bear	Lower Bear Creek	22			20	28	24				24	1
Bear	Daniels Creek			24		22	22				22	1
Bear	Mackey Creek	26			32	34	28				28	1
Bear	NE 148th at Mink Rd.			32	38						38	4
Bear	NE 148th at Mink Rd. - upstream			34							34	4
Bear	NE 164th St at Mink Rd.			36							36	4
Bear	Woodinville/Duvall at 210th Ave NE			32							32	4
Bear	At Paradise Road								16		16	3
Bear	3312								34	32	32	2
Bear	3321								26	28	28	2
Bear	3325/ BEAR 13								20	30	30	2
Bear	3478/ BEAR 15								24	34	34	2
Bear	3571								30	32	32	2
Bear	3650/ BEAR 02								30	34	34	2
Bear	3737								28	36	36	2
Bear	3747/ BEAR 03	26				20	14		26	32	32	1, 2
Bear	3826								34	34	34	2
Bear	3914								32		32	2
Cottage Lake	Cottage Lake Creek	36	28	26		30	22				22	1
Bear	Lower Evans Creek					28	24				24	1
Bear	Middle Evans Creek		26	26	18	24	26		24		24	1, 2

Water Body	Site Name, Number, or Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	Recent	Source
Evans	4077								30		30	2
Evans	3474								16	20	20	2
Evans	3555								32	32	32	2
Evans	3637								28	18	18	2
Evans	3640								28	28	28	2
Evans	3642								22		22	2
Evans	3813								28		28	2
Evans	4249			30		22	28		32	20	20	1, 2
Forbes	108th Ave. NE and Forbes Creek Drive			16						16	16	4
Forbes	NE 106th and Forbes Creek Drive			16							16	4
Forbes	2191								14	16	16	2
Issaquah	3958								42	36	36	2
Issaquah	4294								38		38	2
Issaquah	4373	30			32		28		24	32	32	1, 2
Issaquah	4573								40	44	44	2
Issaquah	4735								40	42	42	2
Issaquah	4884								42	48	48	2
Issaquah	Lower Issaquah Creek	36	28		34		34				34	1
Issaquah	Upper Issaquah Creek	32			36		34				34	1
Issaquah	Carey Creek	36	34		40		30				30	1
Issaquah	E. Fork Issaquah Creek		30		36		32				32	1
Issaquah	N. Fork Issaquah Creek		28		34		30	32			32	1
Issaquah	Black Nugget Creek		48		42			32			32	1
Issaquah	Holder Creek			28	32		32		38	38	38	1, 2

Water Body	Site Name, Number, or Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	Recent	Source
Kelsey	2272								10	14	14	2
Kelsey	2546								14	16	16	2
Laughing Jacobs	DS of Sammamish PW SE at SE 43rd Way				22	32					32	4
Laughing Jacobs	US of Sammamish PW SE at SE 43rd Way				30	32					32	4
Little Bear	189th				40				36		36	3, 4
Little Bear	228th			30		28					28	3
Little Bear	51st			34		34	30				30	3
Little Bear	SR 202						28				28	3
Little Bear	Interurban Blvd.						34			26	26	3
Little Bear	180th St. SE and 51st Ave SE			36					22		22	2, 4
Little Bear	196th St. SE and 51st Ave SE				34						34	4
Little Bear	228th St. SE and Hwy. 9			28							28	4
Little Bear	233rd Place SE and Hwy. 9			22	22						22	4
Little Bear	NE 177th Place and 134th Ave. NE				24				26		26	2, 4
Little Bear	NE 178th Street and 130th Ave. NE				22						22	4
Little Bear	NE 195th St. SE and 136th Ave. NE				30						30	4
Little Bear	2602								26	36	36	2
Little Bear	2682								26	28	28	2
Little Bear	2685								24	24	24	2
Little Bear	2692								28	36	36	2
Little Bear	2781								32	30	30	2
Lk. Sam Tribs	2827								18		18	2
Lk. Sam Tribs	3121								10	16	16	2
Lk. Sam Tribs	3879								26	30	30	2

Water Body	Site Name, Number, or Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	Recent	Source
Lk. Sam Tribs	3880								22	38	38	2
Lk. Sam Tribs	3540								22	30	30	2
Lk. Sam Tribs	3616								18	26	26	2
Lk. Sam Tribs	3627								26	26	26	2
Lk. Sam Tribs	3699								38	32	32	2
N. Lk. WA Tribs	1536								26		26	2
North	164th								28		28	3
North	192nd								28		28	3
North	208th								24		24	3
North	Canyon Park Road							16			16	3
North	At County Line			18		16			20		20	3
North	236th St. NE and Fitzgerald Road				22						22	3
North	2028								12	18	18	2
North	2115								16	22	22	2
Sam Riv Tribs	0000								10	18	18	2
Sam Riv Tribs	1914								22		22	2
Sam Riv Tribs	2674								18	20	20	2
Sam Riv Tribs	2855								10		10	2
Sam Riv Tribs	2862								36	38	38	2
Sam Riv Tribs	2865								14	24	24	2
Sam Riv Tribs	2946								22	16	16	2
Sam Riv Tribs	2951								12	14	14	2
Sam Riv Tribs	3045								24	26	26	2
Seidel	NE 133rd St. and 198th Ave. NE				36						36	3

Water Body	Site Name, Number, or Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	Recent	Source
Struve	NE 150th St. and 206th Ave. NE				34						34	3
Issaquah	08ISS4724									44	44	2
Issaquah	08ISSQ04									38	38	2
Issaquah	A631 ISS. CK U/S OF HATCHEM									32	32	2
Juanita	0446 JUANITA									18	18	2
Kelsey	D444 KELSEY CREEK									16	16	2
Little Bear	08LIT2585									28	28	2
Little Bear	0478 LITTLE BEAR									20	20	2
Little Bear	08LIT2876									36	36	2
Kelsey	0444 MERCER SLOUGH									20	20	2
North	0474 NORTH CREEK									24	24	2
North	08NOR1750									28	28	2
North	08NOR2306									20	20	2
Sam Riv Tribs	08SAM3047									24	24	2

Sources:

1. King County Website: http://dnr.metrokc.gov/wlr/waterres/Bugs/datatable.doc
2. King County unpublished data for 2002, 2003, courtesy of King County Water and Land Resources Division
3. Snohomish County Website: http://198.238.192.103/spw_swhydro/wq-search.asp
4. Sarah Morley’s thesis: http://depts.washington.edu/cwws/Theses/morley.pdf

Upland Habitat Connectivity: Habitat connectivity seeks to characterize the flow of energy, materials, and organisms throughout an area that has otherwise been fragmented by human disturbance. Habitat fragmentation can lead to habitat isolation, changes in microclimate, disturbance regime, and species composition (Saunders et al. 1991, Forman 1995). To facilitate our selection of mitigation sites, we examined forested area at the stream catchment scale to target catchments that were "at risk" for habitat connectivity. To explore the proportion and distribution of habitat in the study area, we used FRAGSTATS, a free program developed by McGarigal et al. (2002) to compute landscape metrics (Table C- 8).

Table C-8. FRAGSTATS-calculated landscape metrics used for this project (McGarigal et al. 2002).

Metric	Name	Description
AREA	Area	Area of each patch (ha)
CA	Class Area	Total class area within a landscape (ha)
TA	Total Area	Total landscape area (ha)
PLAND	Percent of Landscape	Percentage of landscape in class (percent)
GYRATE_AM	Area-weighted Mean Radius of Gyration	The area-weighted mean radius of gyration, correlation length, the average distance traversed from a random starting point in a random direction with in a landscape, its traversability (Figure C-3)
COHESION	Patch Cohesion Index	Physical connectedness of patches in a class, approaches 0 as class becomes less aggregated (comparative value, Figure C-2)

Using 1998, 30-meter resolution, classified Landsat imagery, we examined the existing forest cover in the study area (see Figure 34 in the main document, Upland Forest Cover). Forested areas were those with greater than 70 percent forest cover, according to the Landsat classification scheme (Hill et al. 2003). We rejected the urban forest classification as forest, as it included obviously urbanized areas such as landscaped yards. Water was our second classification, and everything else was classified as non-forest. Merging the new layer of forest, non-forest, and water classifications with the DAU and stream catchment boundaries, we calculated the percentage of forest for each scale.

The focus of this study is not to target any particular organism for habitat connectivity. Our designation of forest as habitat seeks to encompass natural areas remaining in the study area, those that are more likely to harbor native species, corresponding to the pre-development condition of the landscape. Our intent was not to become species-specific in our management practices, but to gain some understanding of the changes to habitat within the landscape from pre-development to its current state. Habitat connectivity was intended as a method to address the structural connectedness of the remaining habitat patches in the landscape and apply them to ranking of the potential mitigation sites by condition of the stream catchment in which they exist.

We used the Patch Cohesion Index (COHESION) as one of the metrics to assess connectivity, developed by Schumaker (1996). The index is a measure of the physical connectedness of patches in a class, calculated using the perimeter-area ratio divided by the shape index, when both are weighted by patch area (Figure C-2). “Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected” (McGarigal 2002). It takes into account the percentage of the landscape composed of the focal patch, giving a comparative value that approaches 0 as the class becomes more widely dispersed. If the landscape is composed of one patch only, the Patch Cohesion Index gives a value of 100.

$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \cdot (100)$	p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. A = total number of cells in the landscape.

Figure C-2. Patch Cohesion Index.

> “COHESION equals [1 minus {the sum of patch perimeter (in terms of number of cell surfaces) divided by <the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type>}], divided by [1 minus {1 over the square root of the total number of cells in the landscape}], multiplied by 100 to convert to a percentage” (McGarigal et al, 2002).

The Patch Cohesion Index increases with the percentage of habitat until it reaches a percolation threshold, which is near 41 percent using the 8-neighbor rule (Stauffer 1985, Gustafson 1997, McGarigal et al. 2002). At the percolation threshold the Cohesion Index creates an asymptote and there is a high *probability* that the habitat patches form a cohesive, percolating patch network, called a spanning cluster, reaching from one side of the lattice to the other.

> If p is the proportion of the map “occupied” by a chosen patch type (e.g., “habitat” in a binary map of “habitat” and “not habitat”), then for raster maps, the size of the largest connected cluster increases nonlinearly with p; at a critical threshold value $p=p_c$, the largest cluster is likely span to the entire map edge-to-edge and the map *percolates*, i.e., the map is traversable (Christensen 2001).

Nathan Schumaker observed that the Patch Cohesion Index could be generalized for species with a range of territory sizes, or those without territories, and the results would not vary significantly if used at multiple scales (1996). This makes the metric ideal for a general assessment of habitat connectivity across multiple sizes and shapes of stream catchments, without concentration on any particular species.

To compare the average size of patches per stream catchment, we used a metric focused on correlation length, or the average extensiveness of connected cells: the area-weighted mean radius of gyration (GYRATE_AM, Figure C-3). “When aggregated at the class or landscape level, radius of gyration provides a measure of landscape connectivity (known as correlation length) that represents the average traversability of the landscape for an organism that is confined to remain within a single patch." (McGarigal et al. 2002, Keitt et al. 1997). A larger radius of gyration correlates to a larger average patch size, and/or less compact patches spreading across the landscape (McGarigal 2002). In comparison with the percentage of landscape in forested areas (PLAND), a greater GYRATE_AM score with a high PLAND score would correlate to stream catchments possessing large, spreading habitat patches, while low scores for both metrics would signify an abundance of smaller patches and more fragmentation.

$\mathrm{GYRATE} = \sum_{r=1}^{z} \frac{h_{ijr}}{z}$	h_{ijr} = distance (m) between cell ijr [located within patch ij] and the centroid of patch ij (the average location), based on cell center-to-cell center distance. z = number of cells in patch ij.

$\mathrm{AM} = \sum_{j=1}^{n} \left[x_{ij} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right]$	AM (area-weighted mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric value multiplied by the proportional abundance of the patch [i.e., patch area (m^2) divided by the sum of patch areas].

Figure C-3. The area-weighted mean radius of gyration (GYRATE_AM).

> The sum, across all patches of the corresponding patch type of the distance (m) between a cell and the centroid of its patch (the average location), based on cell center-to-cell center distance, multiplied by the proportional abundance of the patch [i.e., patch area (m^2) divided by the sum of patch areas] (McGarigal et al, 2002).

The largest forested patch, located in the Issaquah Creek stream catchment, was 7,804 hectares. Over 80 percent of the forested patches in the study area were composed of less than one hectare. Road networks subdivided many of the forested areas. We chose to use an eight-neighbor rule to include linear networks such as riparian corridors and habitat patches shaped by lines of human development.

Ranking the stream catchments by the percentage of landscape in forest (PLAND) matched the projected patterns of urban growth in the study area. Forest remains along some riparian corridors and in parks, near cities, and the rural areas were generally more forested, corresponding to less development. The Sammamish river floodplain, composed mostly of farmland, did not contain any significant patches of forest.

When we compared the Patch Cohesion Index to the percentage of forest cover per stream catchment (PLAND), we found an asymptote in the stream catchment array when greater than 41 percent of landscape was composed of forest, the percolation threshold for an 8-neighbor rule (Gustafson 1997, McGarigal 2002, Figure C-4). The stream catchments to the right of the percolation threshold had a higher percentage of land in forest, and also a high value for Patch Cohesion, indicating a high probability of a spanning cluster, or percolation. Organisms in percolating stream catchments are more likely to be able to cross the landscape using habitat patches. Below the percolation threshold the stream catchments had less cohesive patches, the patches were less physically connected, and there is less possibility that a spanning cluster exists.

Using the graph of Patch Cohesion per PLAND, we modified the stream catchment points to show a circle signifying the GYRATE_AM score (Figure C-5). Larger circles for the area-weighted mean radius of gyration meant a greater proportion of large patches in the landscape. Using metrics describing the density of habitat (PLAND), relative size of habitat patches within the landscape (GYRATE_AM), and the physical connectedness of the habitat patches (COHESION), we then established delineations for “properly functioning,” “at risk,” and “not properly functioning” stream catchments for habitat connectivity. Table C-8 shows the resulting rankings for upland habitat connectivity per stream catchment within our study area (Figure 35, Final Condition Map for Upland Habitat Connectivity).

Table C-8. Upland Habitat Connectivity rankings for each stream catchment.

Stream Catchments	Ranking
Issaquah Creek	Properly Functioning
Tibbetts Creek	Properly Functioning
East Fork Issaquah Creek	Properly Functioning
Evans Creek	Properly Functioning
Bear Creek	Properly Functioning
North Fork Issaquah Creek	At Risk
Cottage Lake Creek	At Risk
Lake Washington North	At Risk
Little Bear Creek	At Risk
East Lake Sammamish	At Risk
Yarrow Creek	At Risk
Mercer Slough	At Risk
Sammamish River	At Risk
North Creek	At Risk
West Lake Sammamish	At Risk
Kelsey-Mercer Creek	At Risk
Richards Creek	Not Properly Functioning
Forbes Creek	Not Properly Functioning
Juanita Creek	Not Properly Functioning

Lake Washington South	Not Properly Functioning
Sturtevant Creek	Not Properly Functioning
Lake Washington Kirkland	Not Properly Functioning

Note: Based on Patch Cohesion and Radius of Gyration per percentage of landscape in forested areas.

We found some gaps between the drainage analysis unit designations, smaller subset regions within the stream catchments designated by a contracted company for the Washington State Department of Transportation. These gaps and slivers created holes in the stream catchment data set. Most of these holes were less than one meter^2 in total area, so it was assumed that the holes would disappear when we clipped the Landsat 30-meter data to the stream catchment borders. A remnant of a mistake in topology, the gaps were too difficult to remove individually. Topology will be taken into consideration on the next project the watershed characterization team attempts, and will undergo considerable quality control before implementation.

The Landsat imagery and aerial photography we used were dated to 1998 – six years before the current watershed characterization. Since then, there has been a population explosion in the area, development has blossomed, and there are undoubtedly discrepancies between the 1998 forest cover and the current conditions. To account for this, we are going to do some on-site evaluation.

Of course, the existence of habitat is not a black or white, binary landscape, as presented here, but follows a more natural gradient. Depending on the species of consideration, some “urban forest” (not included in the Landsat forest designation) could be considered habitat, while some recent clear-cuts (Landsat designated as forest in 1998 but recently logged) would not be considered habitat. The remaining habitat patches are often bounded by straight-line pavement and development, which can have an effect on the composition of species within a habitat patch. However, we did not set out to target any particular species, but to provide a general basis for ranking the existing conditions of the stream catchments within our study area.

This was our first attempt at utilizing the spatial pattern analysis program, FRAGSTATS, to look at upland habitat connectivity. Borders can effect the calculation of some metrics, such as those dealing with nearest-neighbor, as the program bounces off the edge of the landscape, and the reported values may not be as precise. In addition, upland habitat connectivity is only considered within the borders of the stream catchment, and any connection to the adjoining stream catchment is ignored, though habitat may link the two catchments. These concerns will be addressed in future studies.

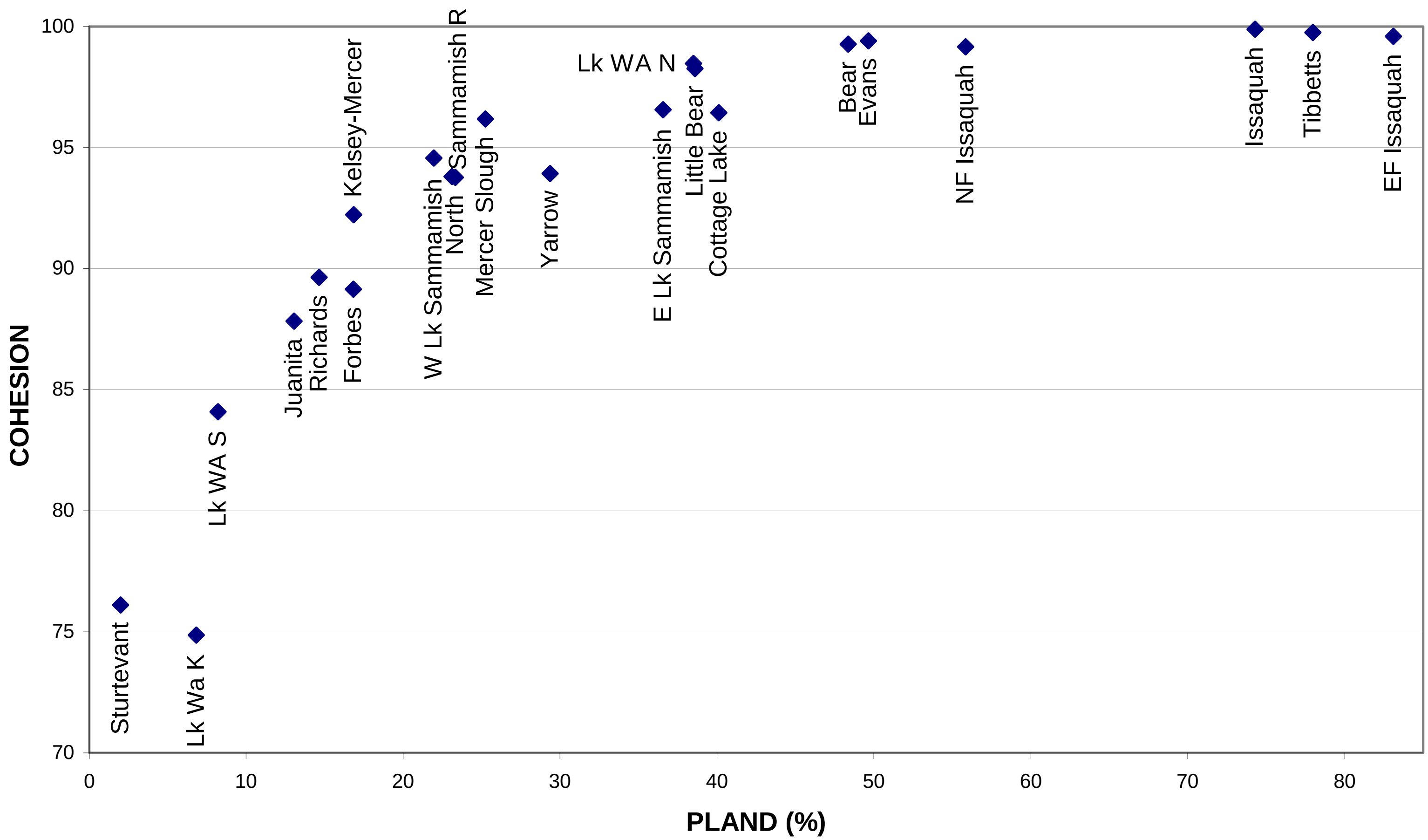

Figure C-4. Patch Cohesion Index (COHESION) for each stream catchment.

Note: By the percentage of that landscape in natural area (PLAND).

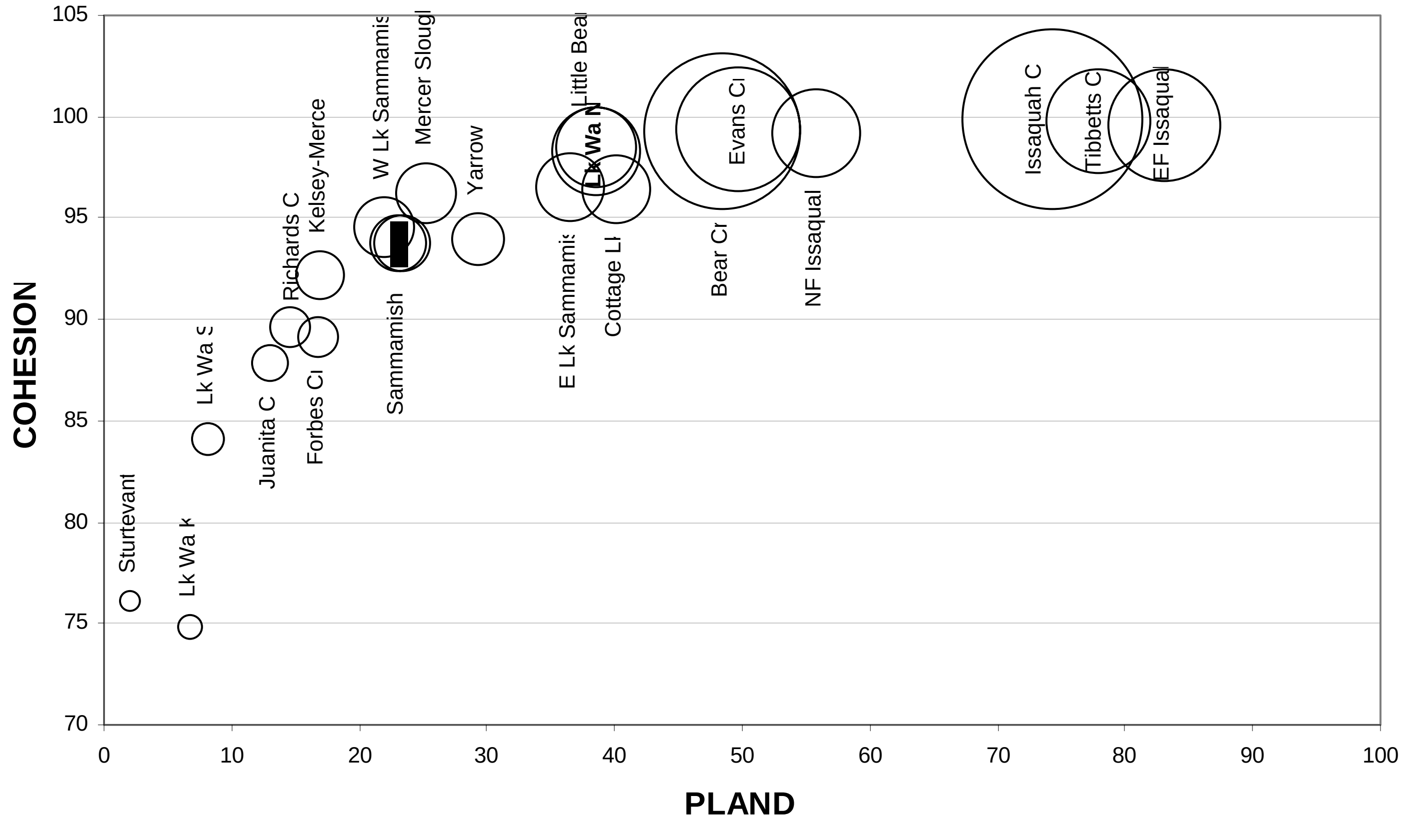

Figure C-5. Patch Cohesion Index (COHESION) for each stream catchment.

Note: By the percentage of that landscape in natural area (PLAND), weighted by the area-weighted mean radius of gyration (GYRATE_AM).

Maps Used Only in This Appendix

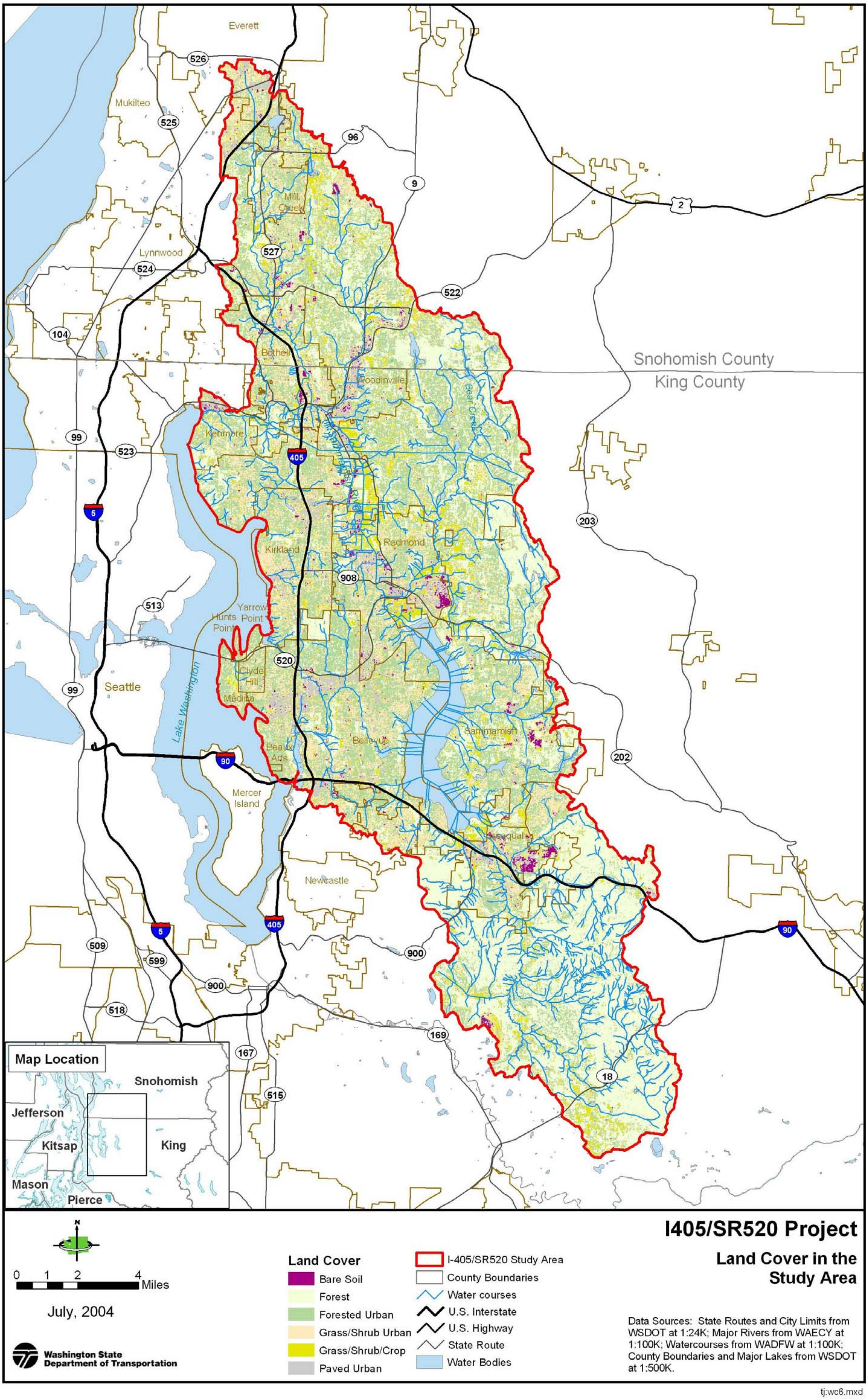

Figure C-6. Current Land Cover.

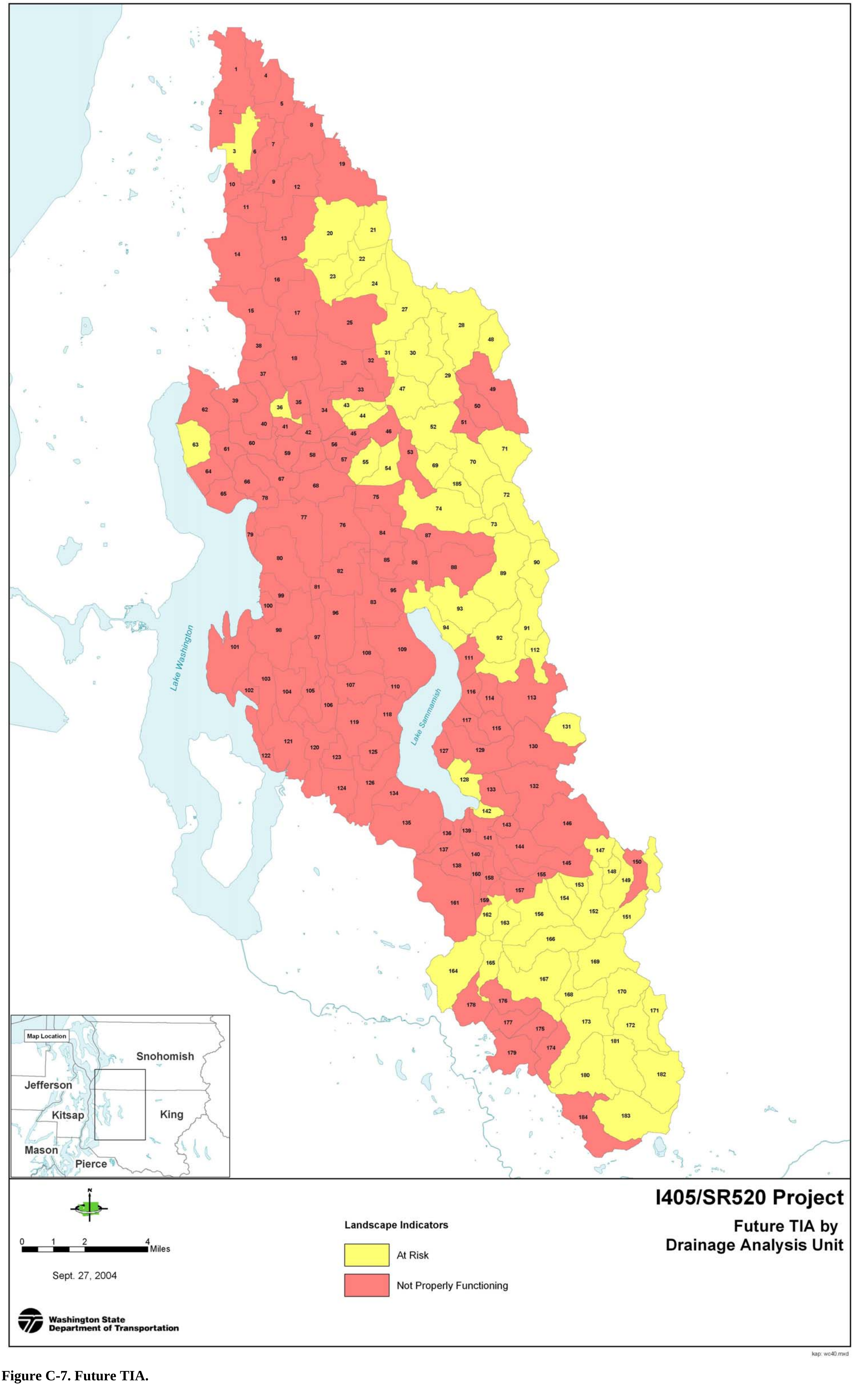

Figure C-7. Future TIA.

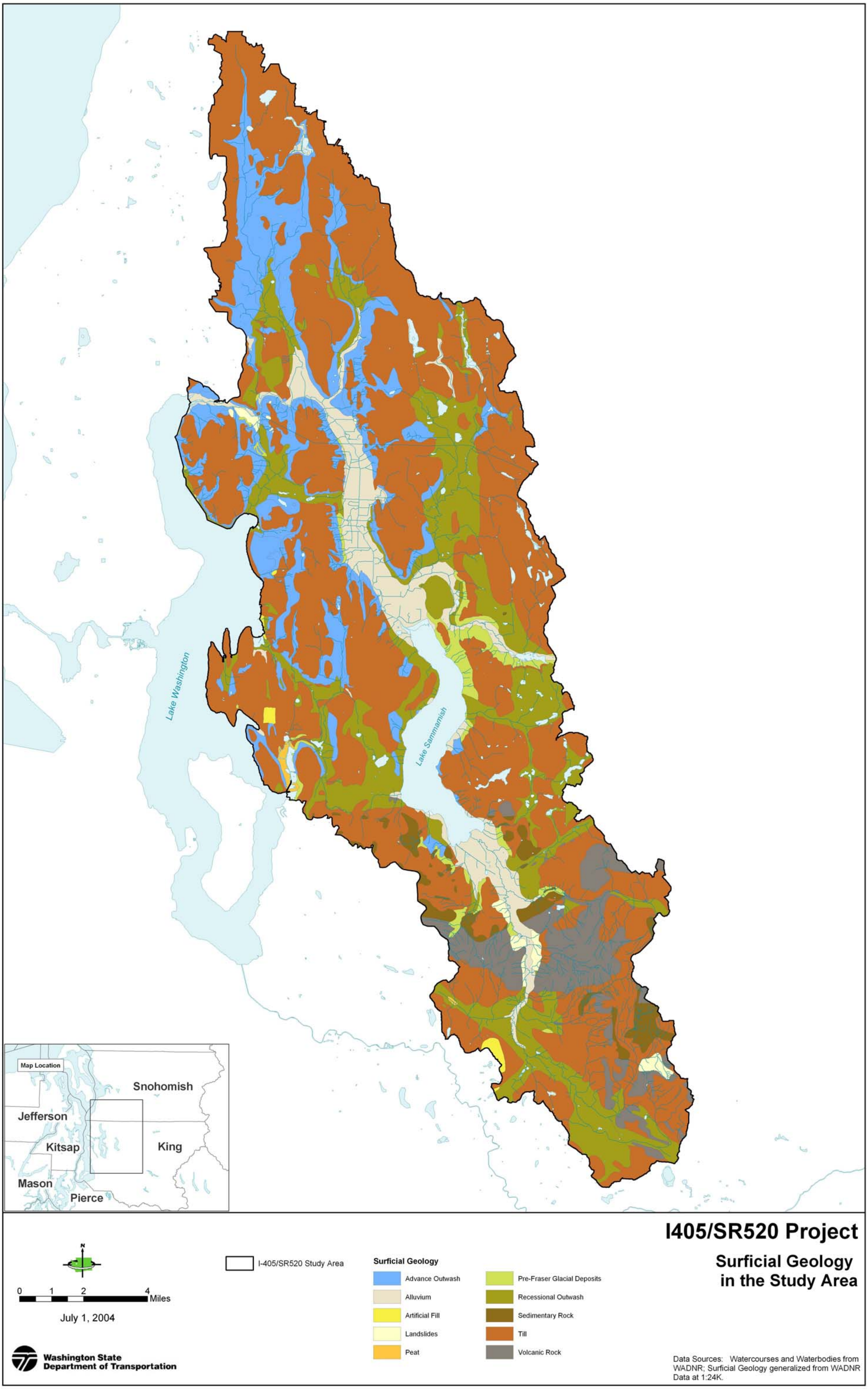

Figure C-8. Surficial Geology in the Study Area.

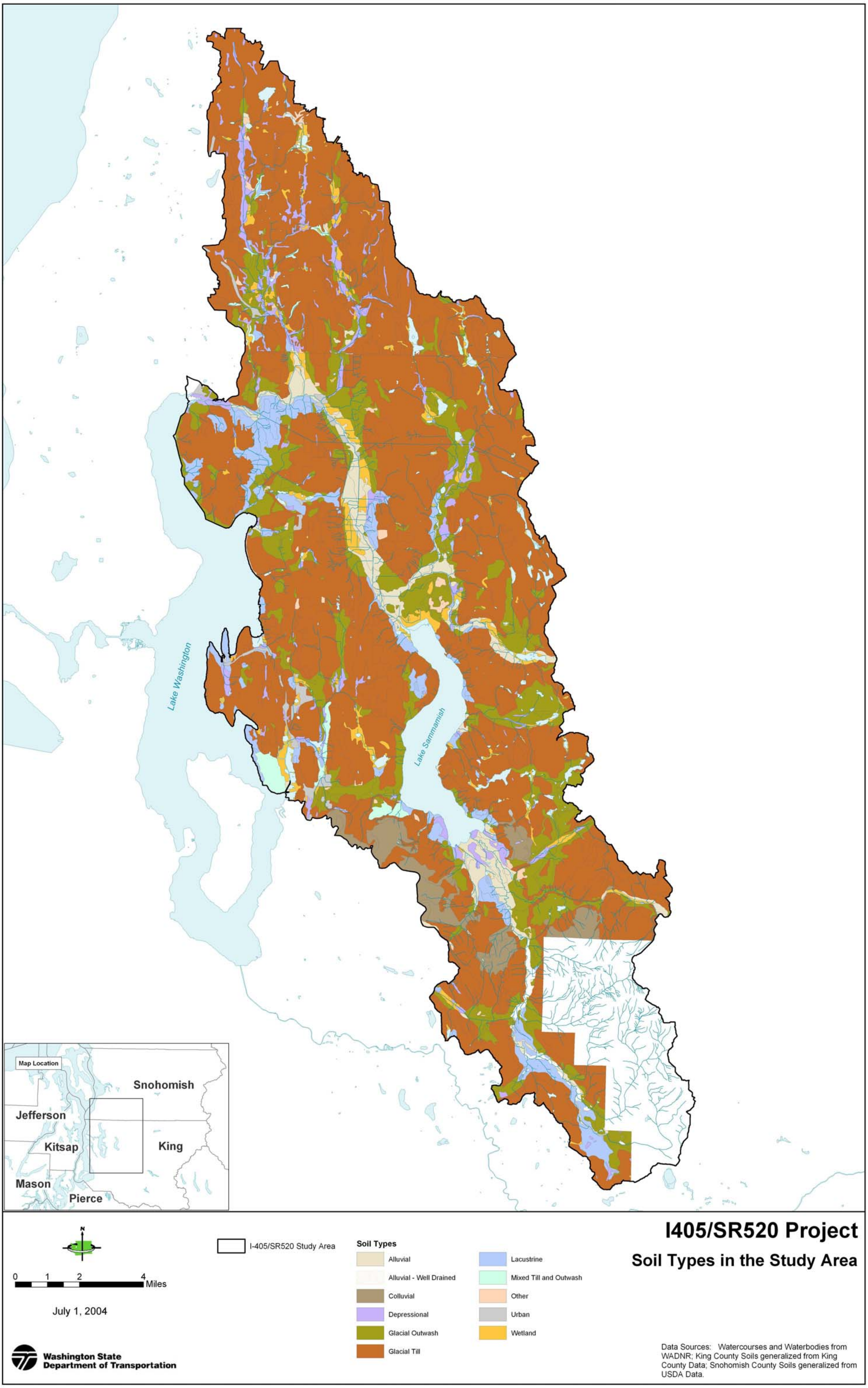

Figure C-9. Soil Types in the Study Area

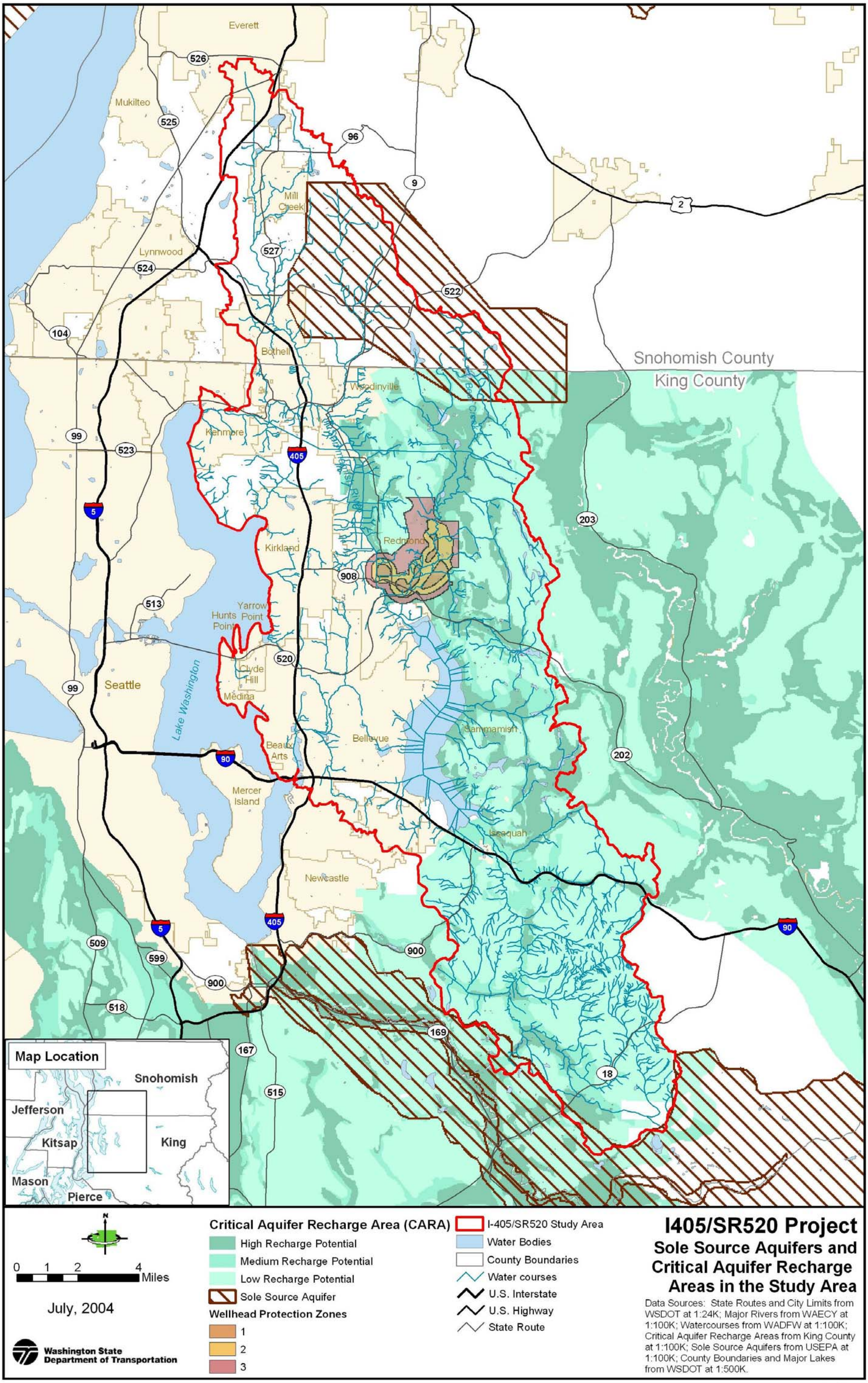

Figure C-10. Sole Source Aquifers and Critical Recharge Areas in the Study Area.

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